Technical overview

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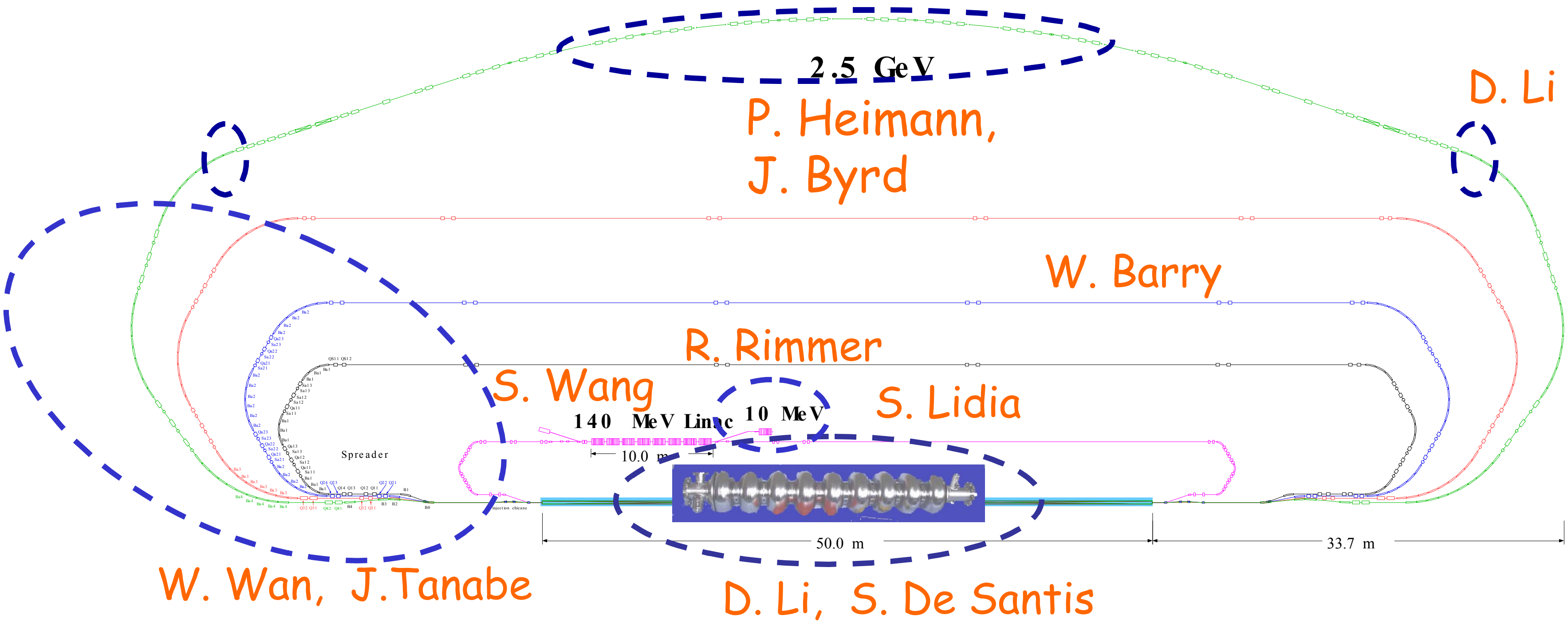
What do users want?

How we are going to meet their demands with a present day accelerator technology?

- Goal: A dedicated ultra-fast x-ray user facility with characteristics driven by scientific needs in Physics, Chemistry and Biology:
  - High time resolution: 60 fs (FWHM)
  - High flux: 3×10^{10} photon /s 0.1% bw at a bunch repetition rate < 10kHz
  - Wide photon energy range: 1 keV to 12 keV, tunable
  - Synchronized to optical lasers
  - Many undulator and bend magnet photon beamlines
- Constraints
  - A user facility, not an accelerator development project
    - Must be based on proven, robust technology

A schematic of the machine and areas of our studies



Recent advances in the accelerator technology in:

- RF superconducting linear accelerators,
- High brightness photocathode electron guns and electron guns with a flat beam in particular,

lay ground for this project

Advantage of a linear accelerator

Bright electron beams from a photocathode gun:

(BNL, SLAC, LANL, UCLA, FNAL, Boeing, CERN, DESY, …)

Q=1nC,

transv. emit. = $2x10^{-4}$ cm,

long. emit.=$8x10^{-3}$ cm (10 ps, 15 keV)

Brightness = $2x10^{19}$ electrons/cm^3

Compare with the ALS beam:

Q=1nC,

transv. emit. = $1.5x10^{-3}$ cm / $3x10^{-5}$ cm ,

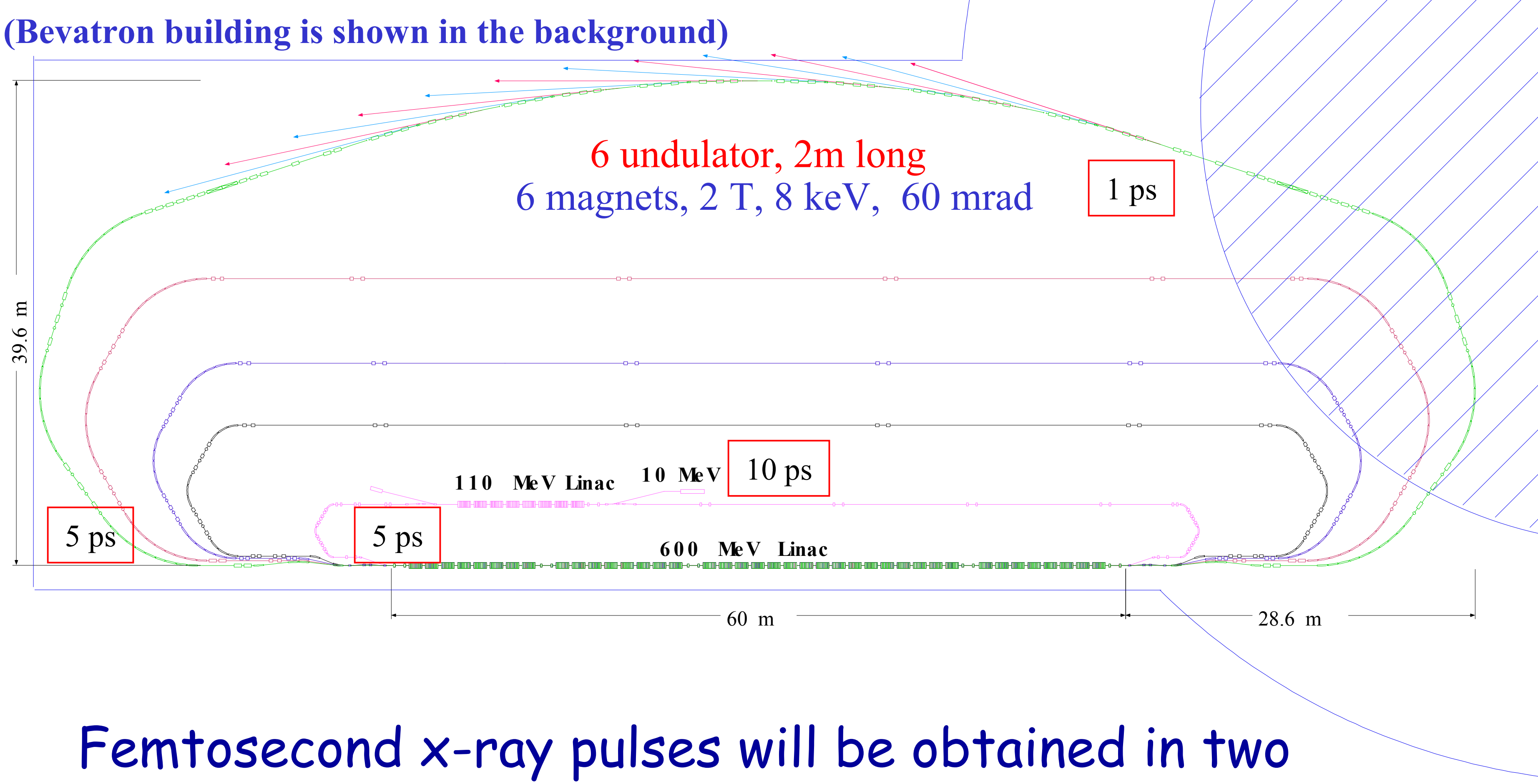
long. emit.=1.5 cm (15 ps, 1900 keV)

Brightness = $1x10^{17}$ electrons/cm^3

Disadvantage: low repetition rate

Not a problem for us!

A layout of the 2.5 GeV recirculating linac



Femtosecond x-ray pulses will be obtained in two stages of pulse compression:

- electron bunch compression to 1 ps
- x-ray pulse compression to < 100 fs

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Electron beam parameters from the injector

Energy	10 MeV
Charge	1 nC
Normalized rms horizontal emittance	20 mm-mrad
Normalized rms vertical emittance	0.4 mm-mrad
Energy spread at 10 MeV	15 keV
Pulse length (uniform distribution)	10 ps

The RF gun parameters:

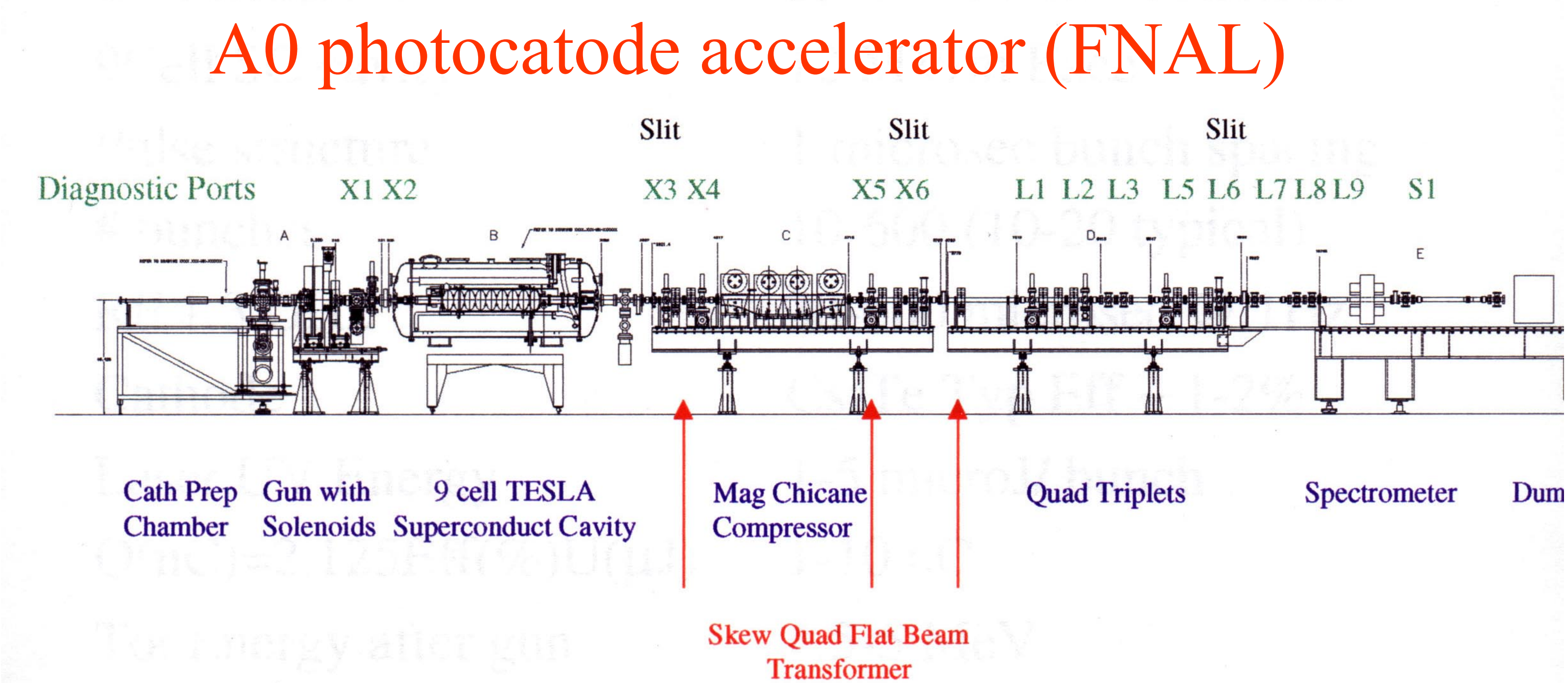
RF frequency	1.3 GHz
Peak electric field on a cathode	60 MV/m
Repetition rate of injection pulses	10 kHz

Laser parameters (an example):

Wavelength (3-rd harmonic of Ti:sapphire laser)	267 nm
Pulse energy	100 μJ
Pulse length (FWHM)	10 ps
Repetition rate	10 kHz

Flat beam from the electron gun (talks by S. Lidia and S. Wang)

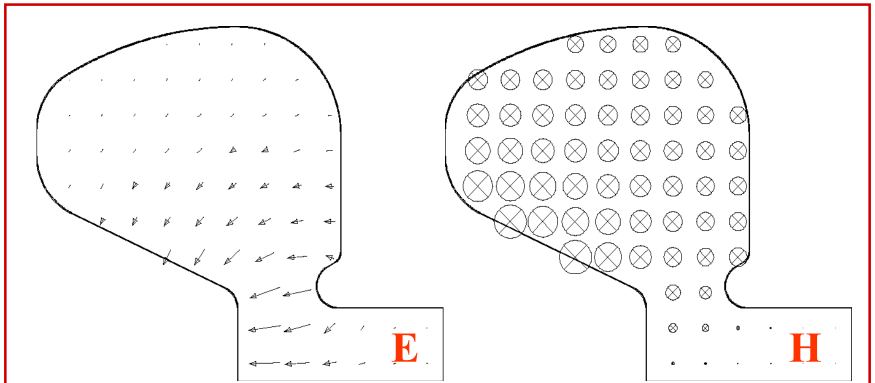
Proposed by Brinkmann, Derbenev, Flötmann



Edwards and co-workers obtained 50 to 1 ratio of the horizontal to vertical emittance

LBNL is collaborating with FNAL in future experiments

High rep. rate gun design (talk by R. Rimmer)

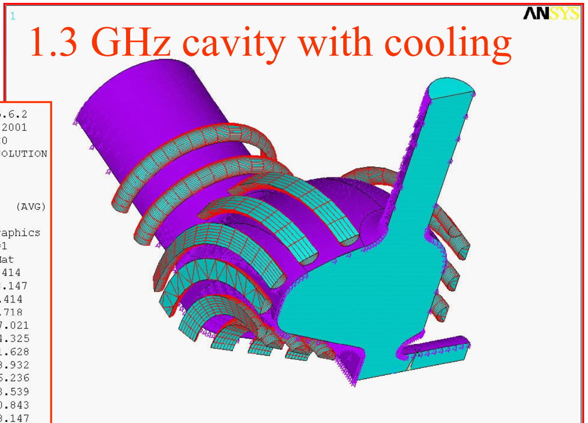


Field calculations for 1.3 GHz cavity

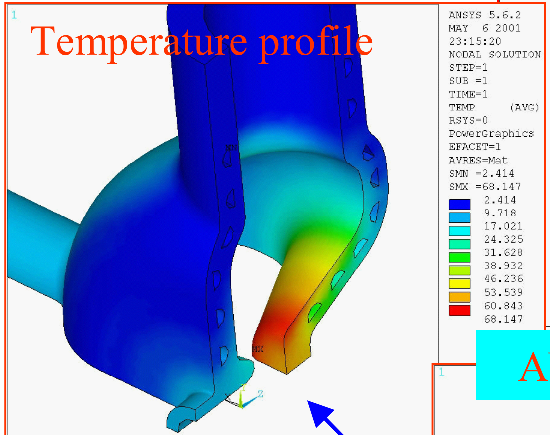
Accelerating voltage at cathode needs to be ~ 40+ MV/m to achieve good beam quality

Gun repetition rate then limited by cavity wall heating

Design cavity for optimal voltage, and wall power density < 100 Wcm^{-2}



1.3 GHz cavity with cooling

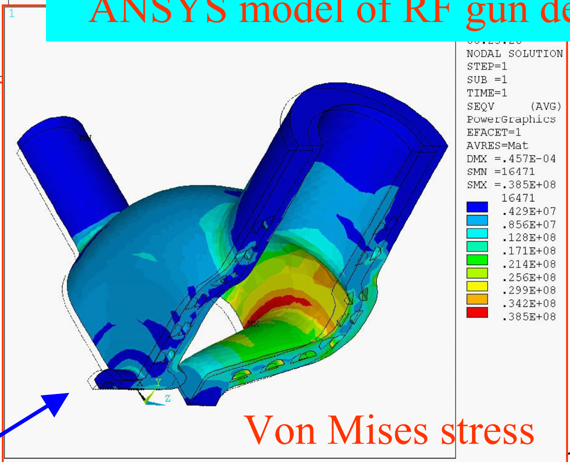


Temperature profile

ANSYS model of RF gun design

gun	freq	Eo cath ..	rep rate	Max Pdens
	(MHz)	MV/m	kHz	W/cm 2
1300	1300	13.8	CW	99.0
	1300	62.0	10	99.9
	1300	40.1	100	99.5
2600	2600	11.0	CW	99.7
	2600	82.6	10	99.8
	2600	53.5	100	99.7
pillbox	1300	13.8	CW	207
	1300	37.8	10	100
	1300	24.6	100	100

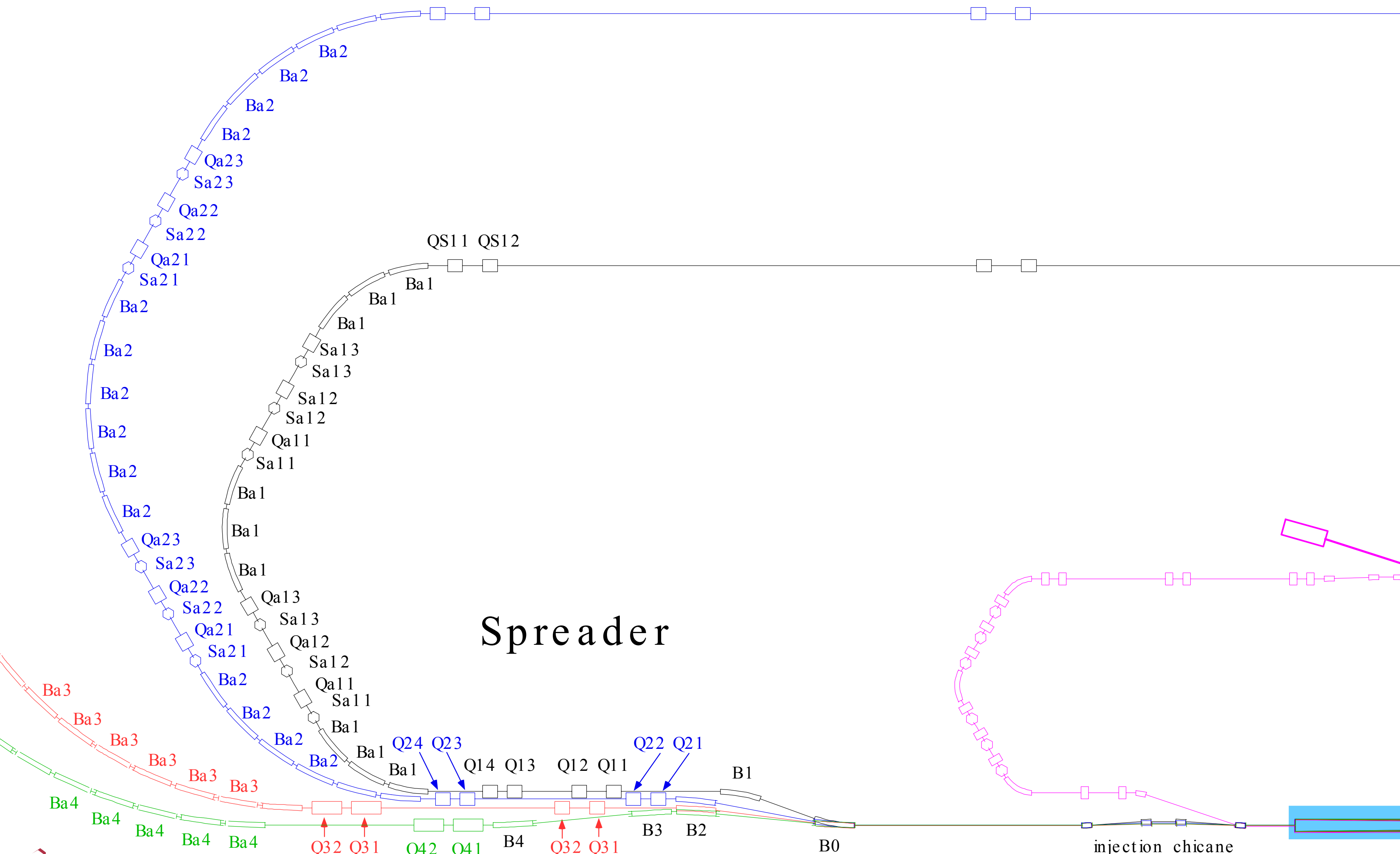
Maximum 68° above ambient temperature



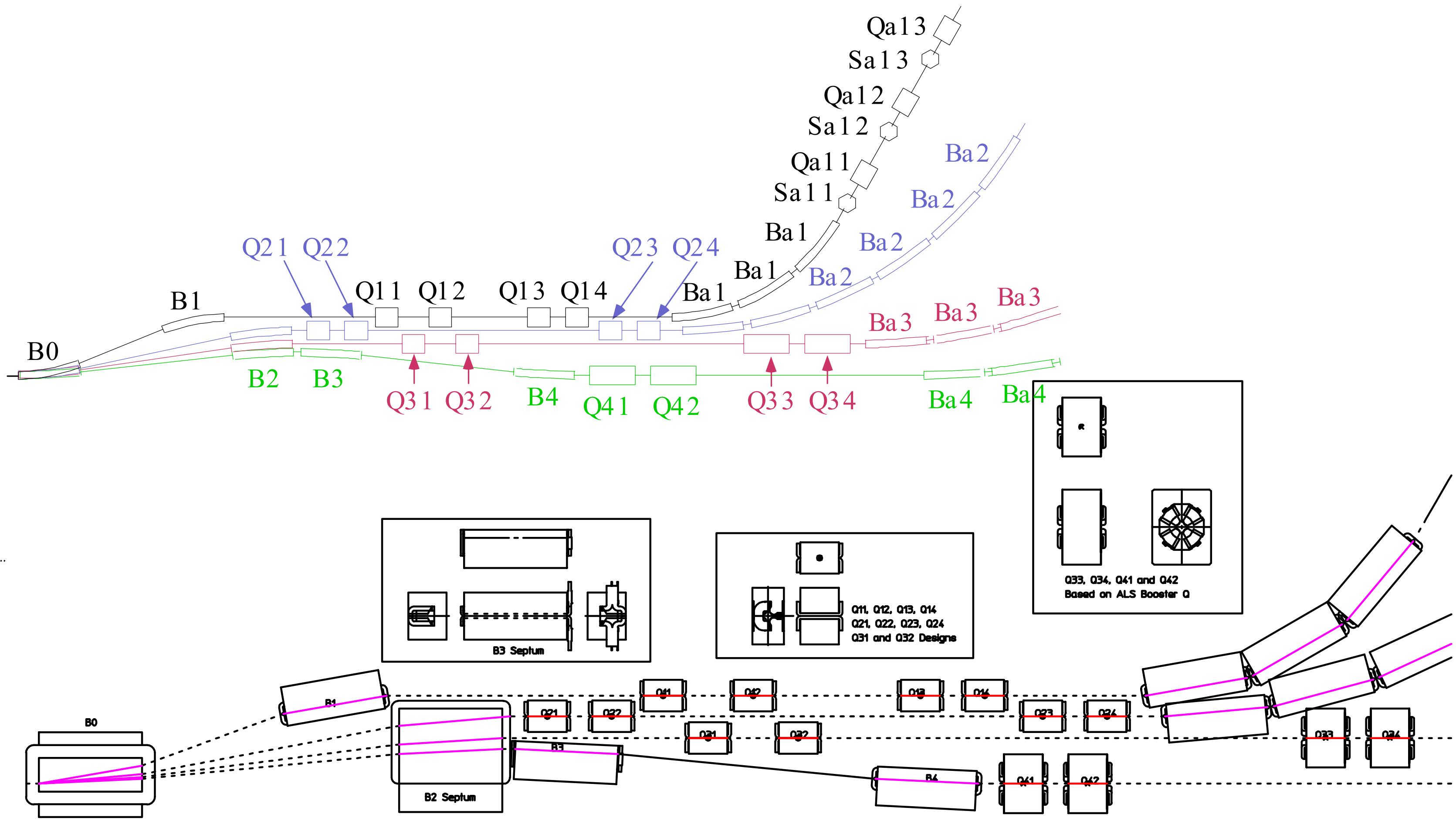
Von Mises stress

Maximum stress 5500 psi safely below "limit" of 18000 psi for 10,000 cycles in Cu

Lattice (talk by W. Wan)



Spreader



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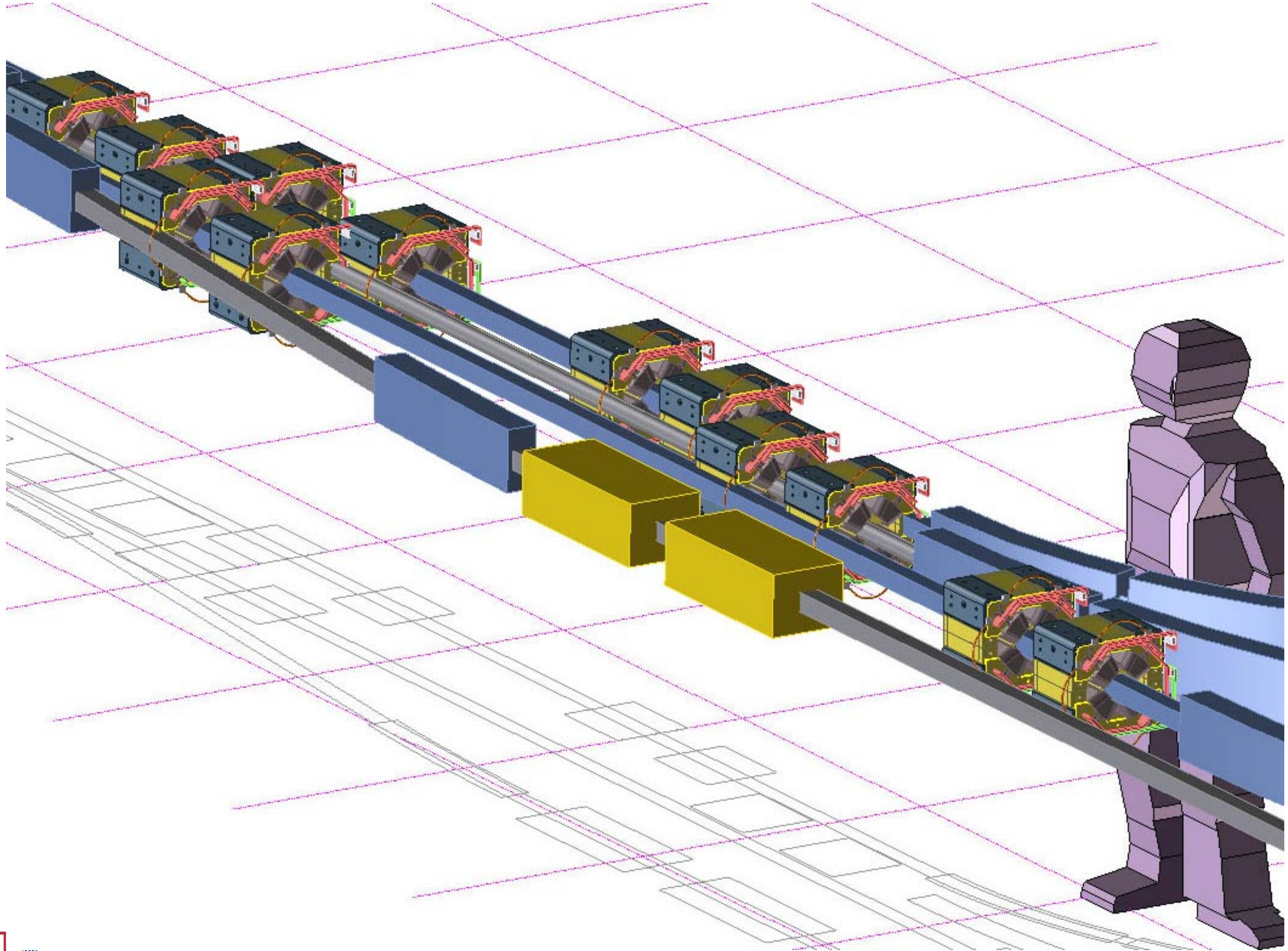
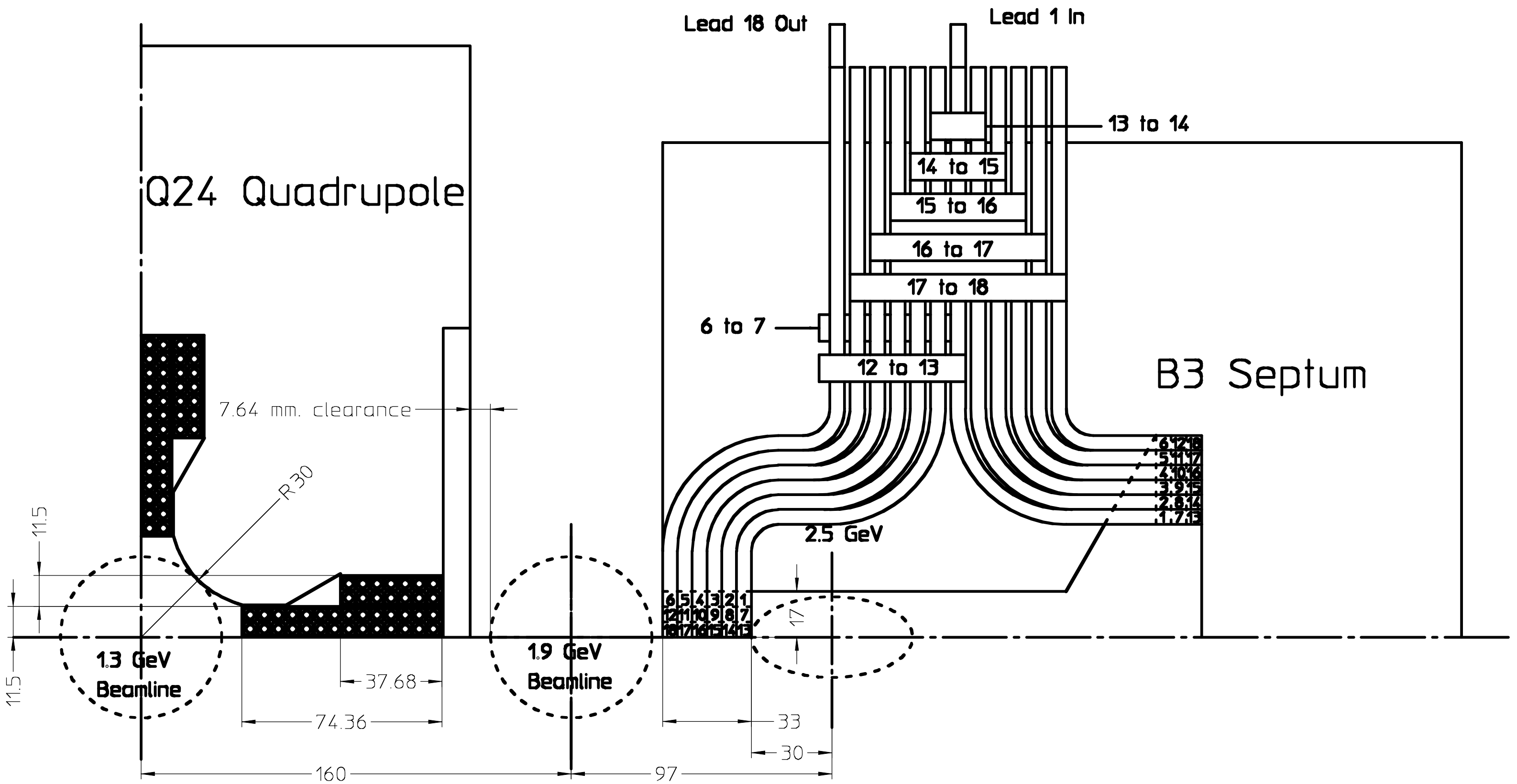
Spreader
Pro-E data base



Magnet design (talk by J.Tanabe)



Septum quadrupole, J=20A/mm^2

Septum magnet, J=50A/mm^2

LINAC Technology

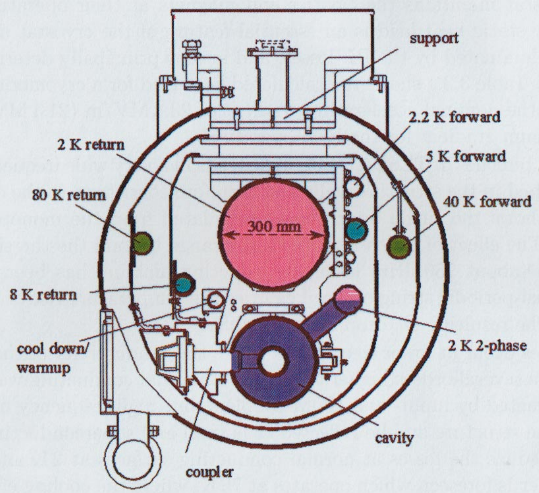
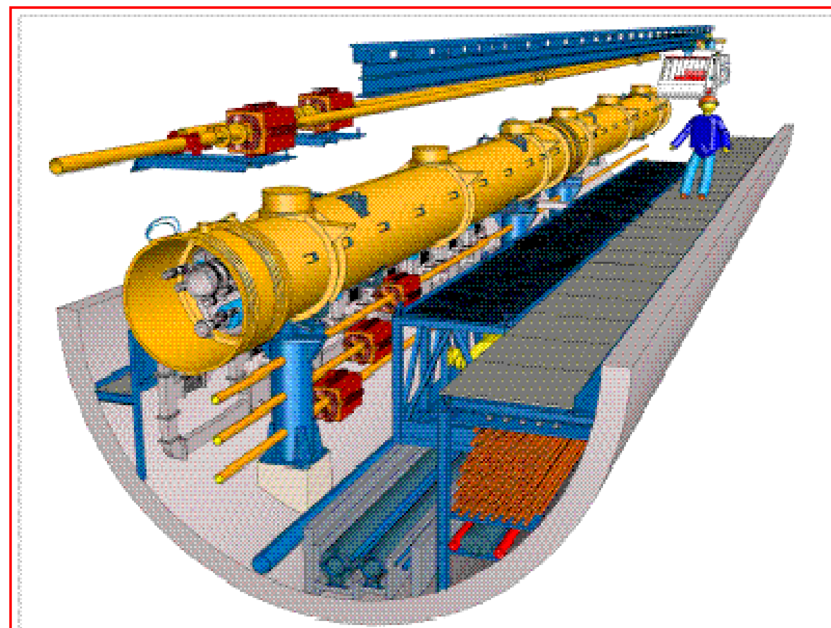


Figure 3.3.2: *Cross section of cryomodule.*

- **superconducting linac developed for DESY Linear Collider TESLA with industry**

  - 42 MV / m accelerating gradient achieved in a single cavity



TESLA superconducting RF modules

SC 600 MeV Linac (talk by D.Li)

E_{acc}	20 MV/m
Frequency	1.3 GHz
Operation mode	CW
Quality factor	$1x10^{10}$
RF power loss/cavity	42 W
Cavity length	1.038 m
Module length	12 m
Cavities/module	8
Beam current	0.04 mA
Q_{beam}	$6x10^{8}$
Bandwidth	200 Hz
$Q_{external}$	$6.5x10^{6}$
RF power/4 modules	540 kW
RF power loss/4 modules	1.3 kW

9-cell superconducting cavity for TESLA: gradient E_{acc}=23 MV/m

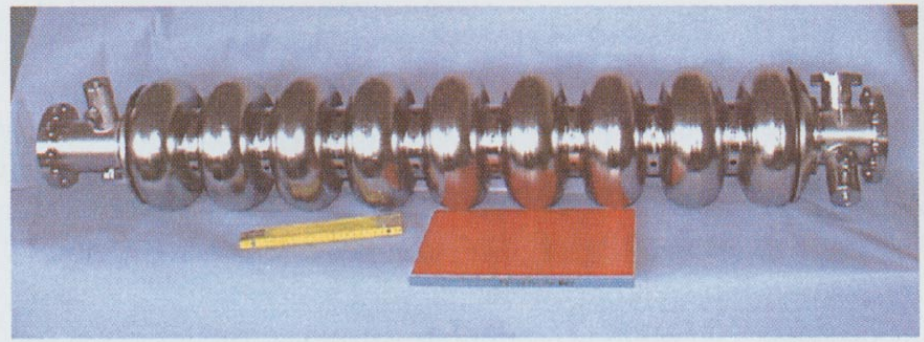
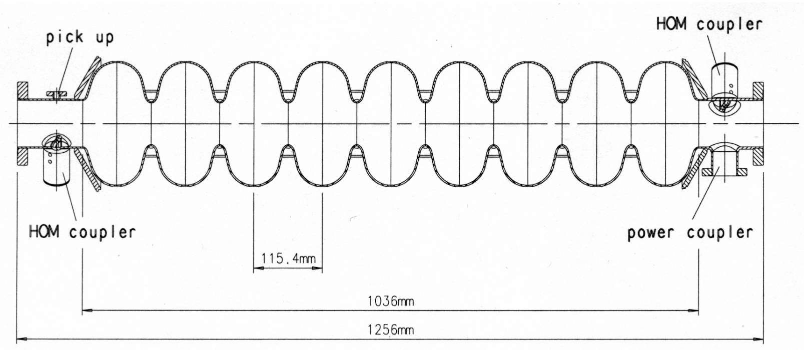


Figure 1.1.1: *The 9-cell niobium cavity for TESLA.*



Transverse instabilities in a recirculating linac
(talk by S. De Santis)

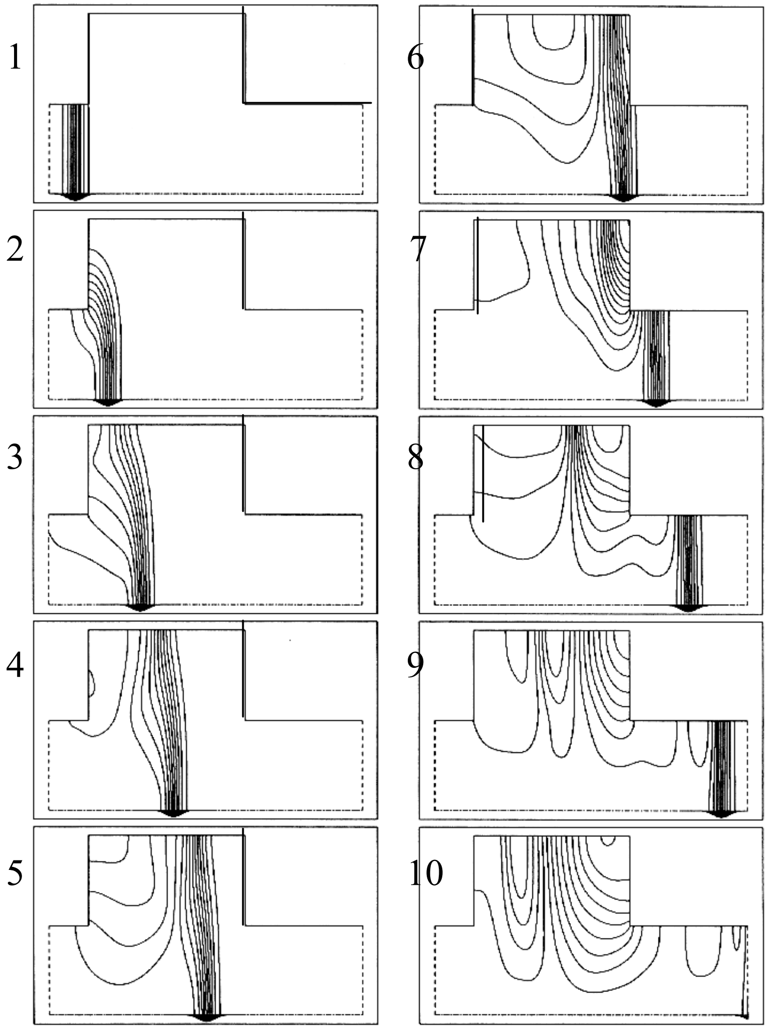
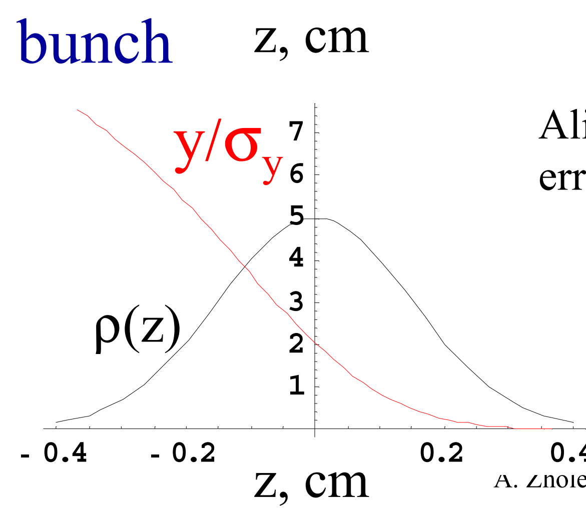


Figure 2.1: Electric field lines of Gaussian bunch passing a pillbox cavity with side tubes.

Average current = 40 μA
Peak current = 200 A
Average linac beta-function = 35 m

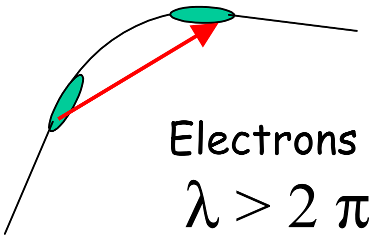
- Single bunch, multi pass- cumulative beam break up
- Multibuch beam break up
  - (define vacuum and cooling requirements)
- Resistive wall wake
- Coherent synchrotron radiation

Single bunch



Alignment rms error = 0.5 mm

Electron bunch compression and CSR



Electrons radiate coherently at

$$\lambda > 2\pi\, l_{bunch}$$

For a rectangular distribution:

number of electrons

magnet length

$$\Delta E = -3^{3/2} \frac{N e^2 L_{mag}}{(l_{bunch})^{4/3} R^{2/3}}$$

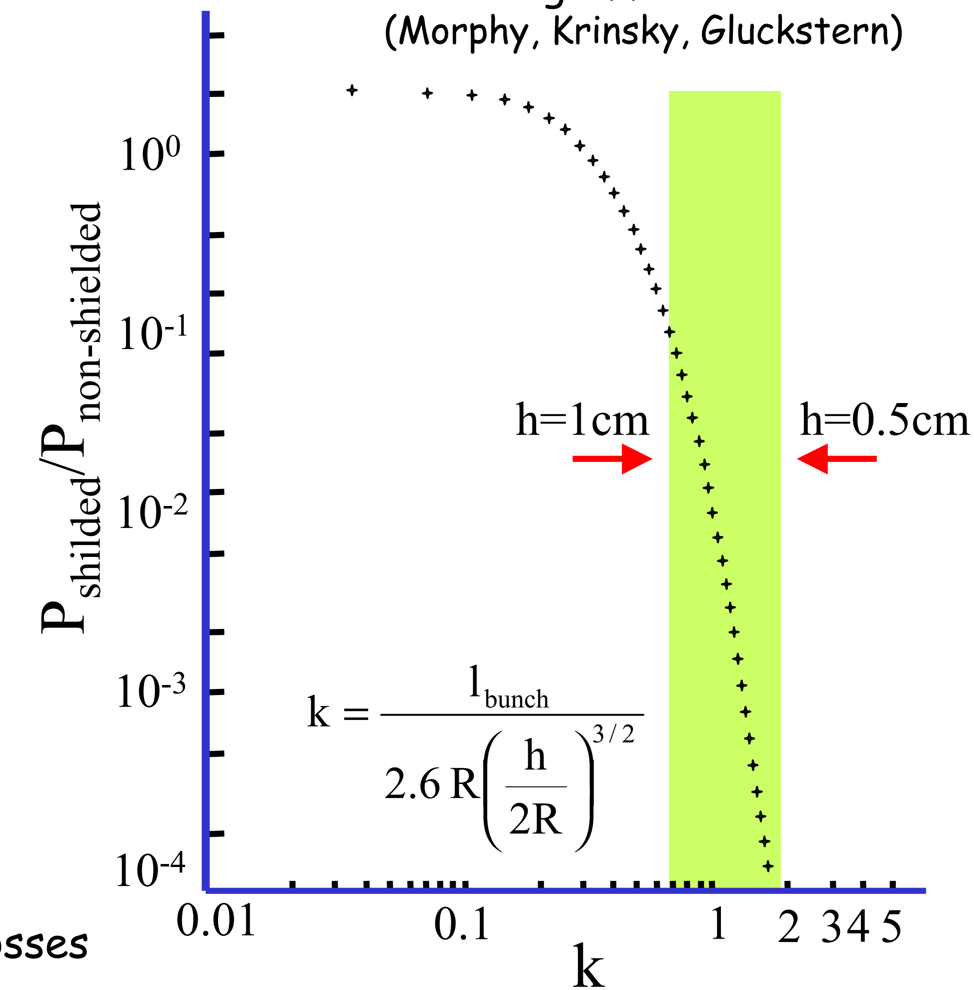
bending radius

For 1nC, 1 ps electron bunch, and
R=4.2m, (2T field), L_{mag}=25 cm:

ΔE=225 keV (rms spread=90 keV)

to be compared with 8 keV of ordinary SR losses
and 150 keV beam energy spread

Shielding effect
(Morphy, Krinsky, Gluckstern)



Too small aperture is not desirable
because of the resistive wall instability
(talk by S. De Santis)

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Energy recovery

Beam power = 10 μA x 2.5 GV= 25 kW

very small, recovery is not required

Deceleration of electrons below energy of giant neutron resonance in materials (< 10 MeV for most of materials) is needed because of the induced radioactivity in the beam dump.

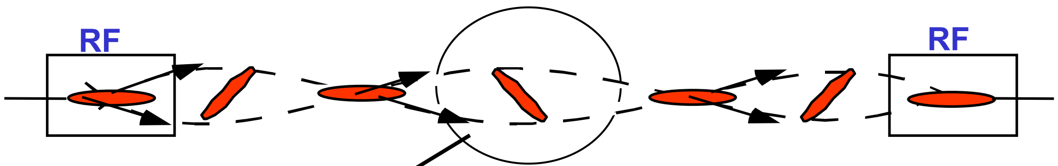
From: A.H.Sullivan et al. "Radioactivity levels near high energy particle accelerators", Nucl. Tech. Publishers, 1992.

Gamma dose rate at 1m from activity induced in various materials per watt of high energy electron beam power loss after one day decay ("cool-off") time: 1 mrem/hour/W (1000 times less after 10 days)

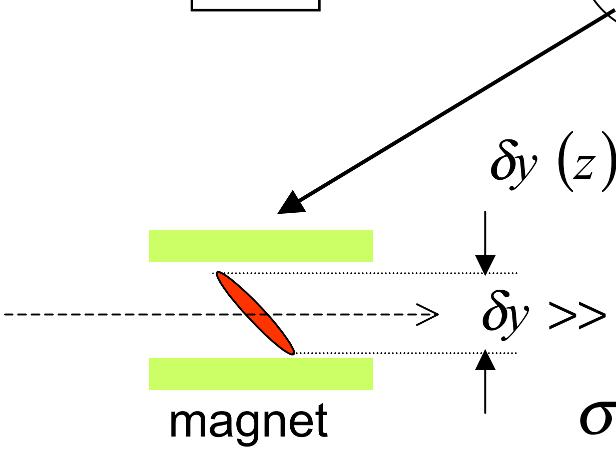
Assuming acceptable level of 100 mrem/hour,
we obtain maximum allowable beam power into dump of 10W

Compression of x-ray pulses (talk by P.Heimann)

is possible due to a correlation between the longitudinal and transverse positions of electrons inside the electron bunch created by the RF orbit deflection in a cavity in the beginning of the final straight section.

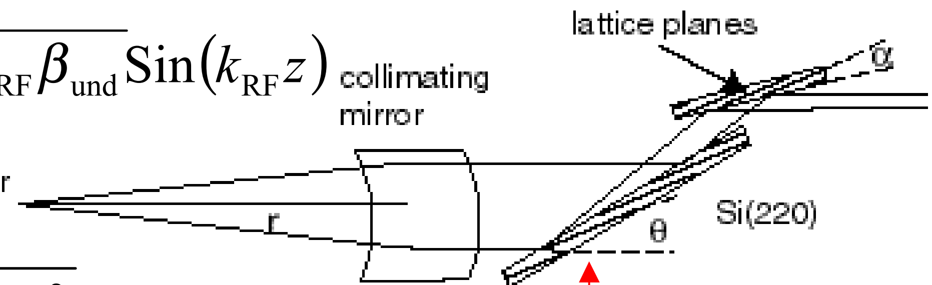


$$\delta y\,(z) = \frac{eU_{\mathrm{RF}}}{E_{\mathrm{b}}}\sqrt{\beta_{\mathrm{RF}}\beta_{\mathrm{und}}}\,\mathrm{Sin}\left(k_{\mathrm{RF}}z\right)$$



$$\delta y >> \sigma_{\mathrm{y}}$$

$$\sigma_{\mathrm{y}} = \sqrt{\sigma_{\mathrm{b}}^{2} + \sigma_{\mathrm{d}}^{2}}$$

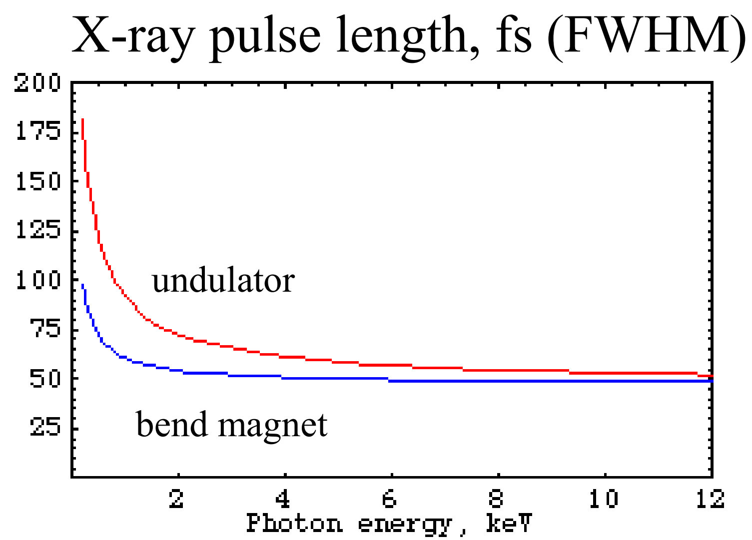


Asymmetrically cut Bragg crystal

Diffraction limited size of a source at $\lambda \approx 1$Å: σ_{d} ~3 µm

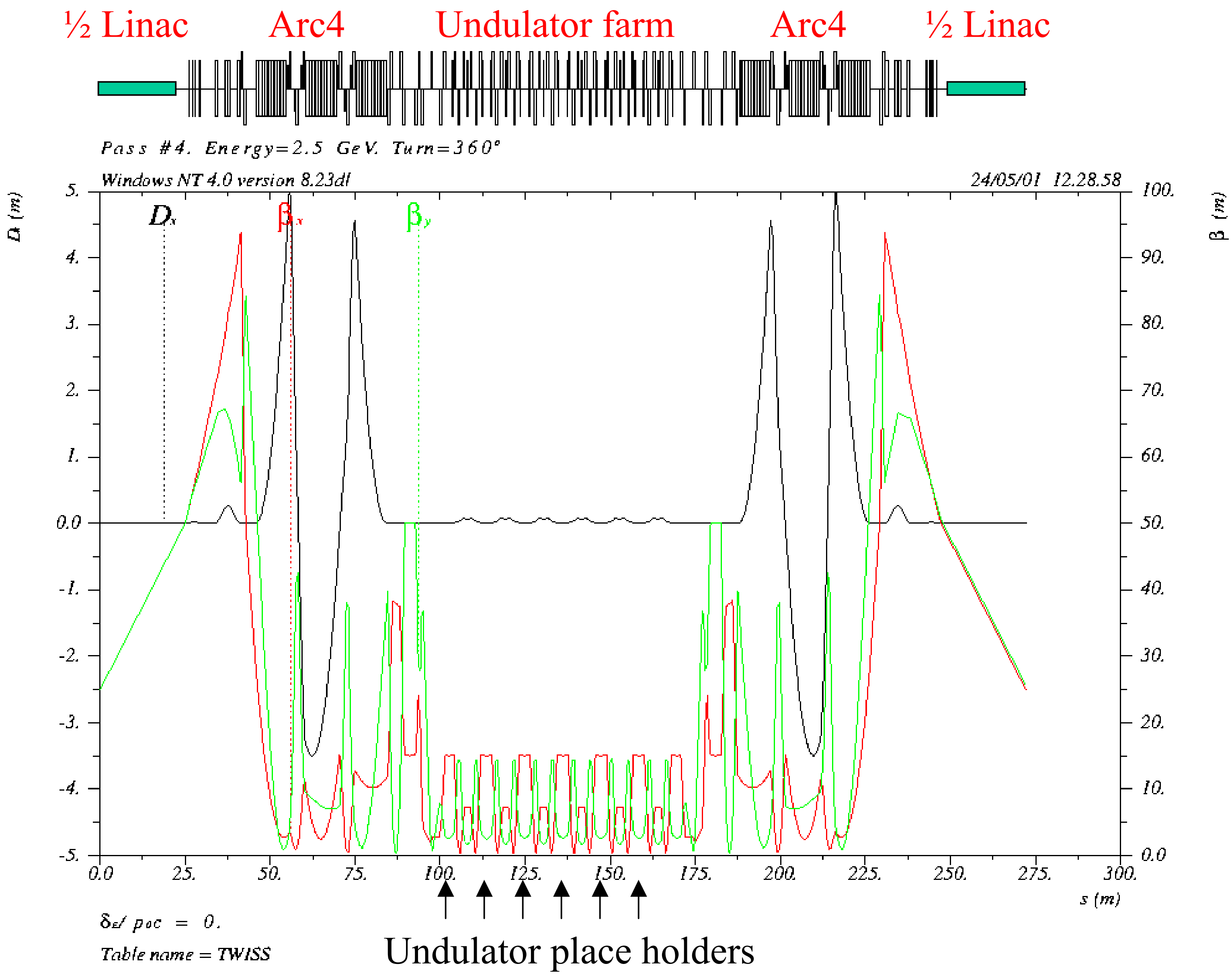
Beam size at ε_{n}=0.4 mm-mrad: σ_{b} ~14 µm

X-ray pulse length



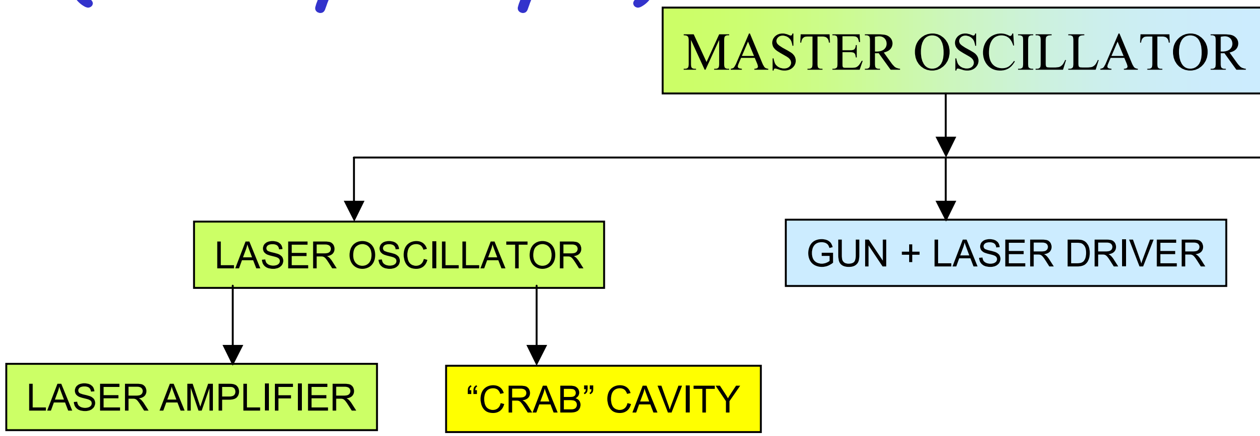
Flat beam with normalized emittances:
vertical = 0.4 mm-mrad;
horizontal = 20 mm-mrad

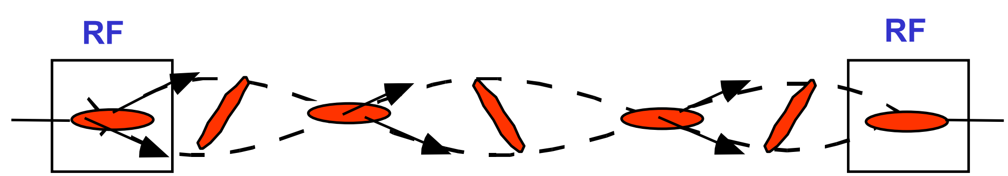
Needs U_{rf}=6.5 MV at f_{rf}=3.9 GHz



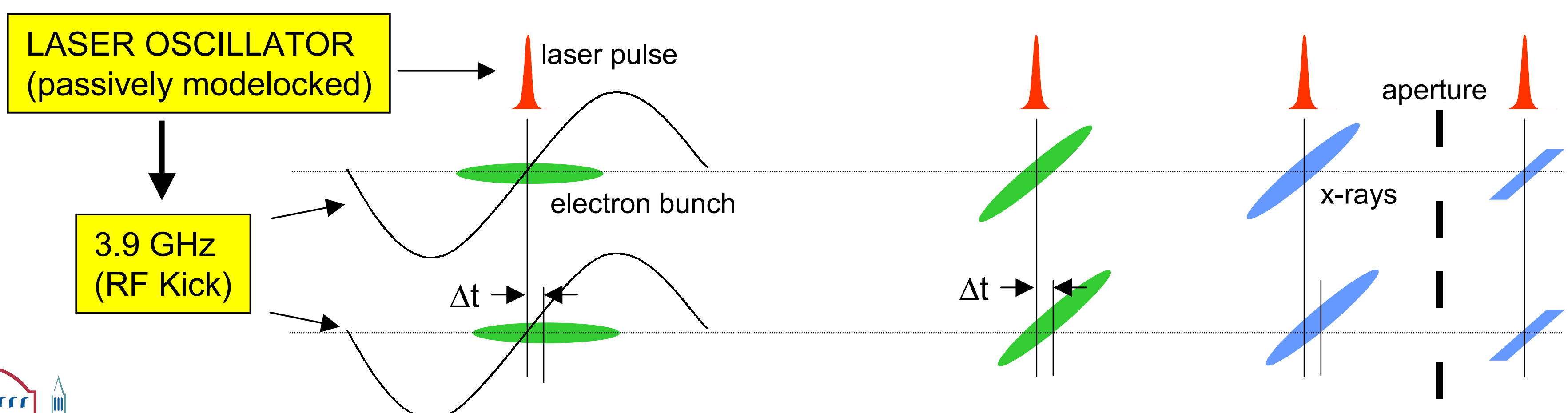
Optical functions

Synchronization of optical and x-ray pulses (talk by J.Byrd)

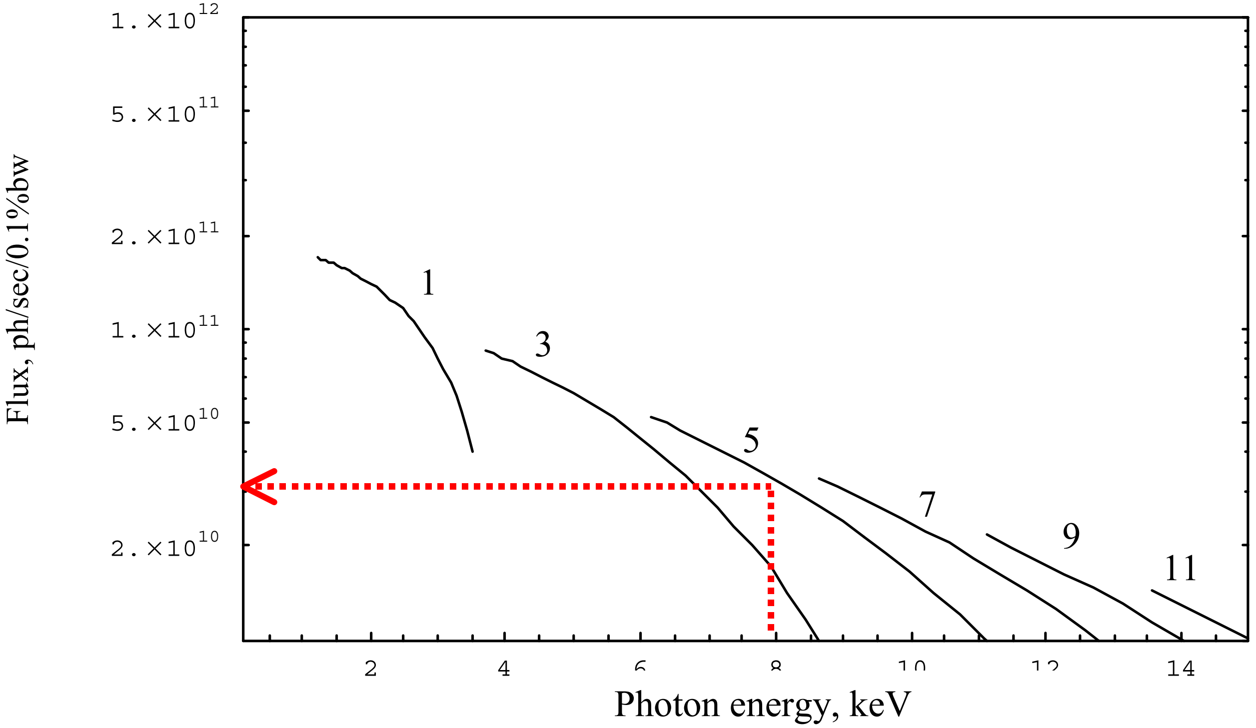




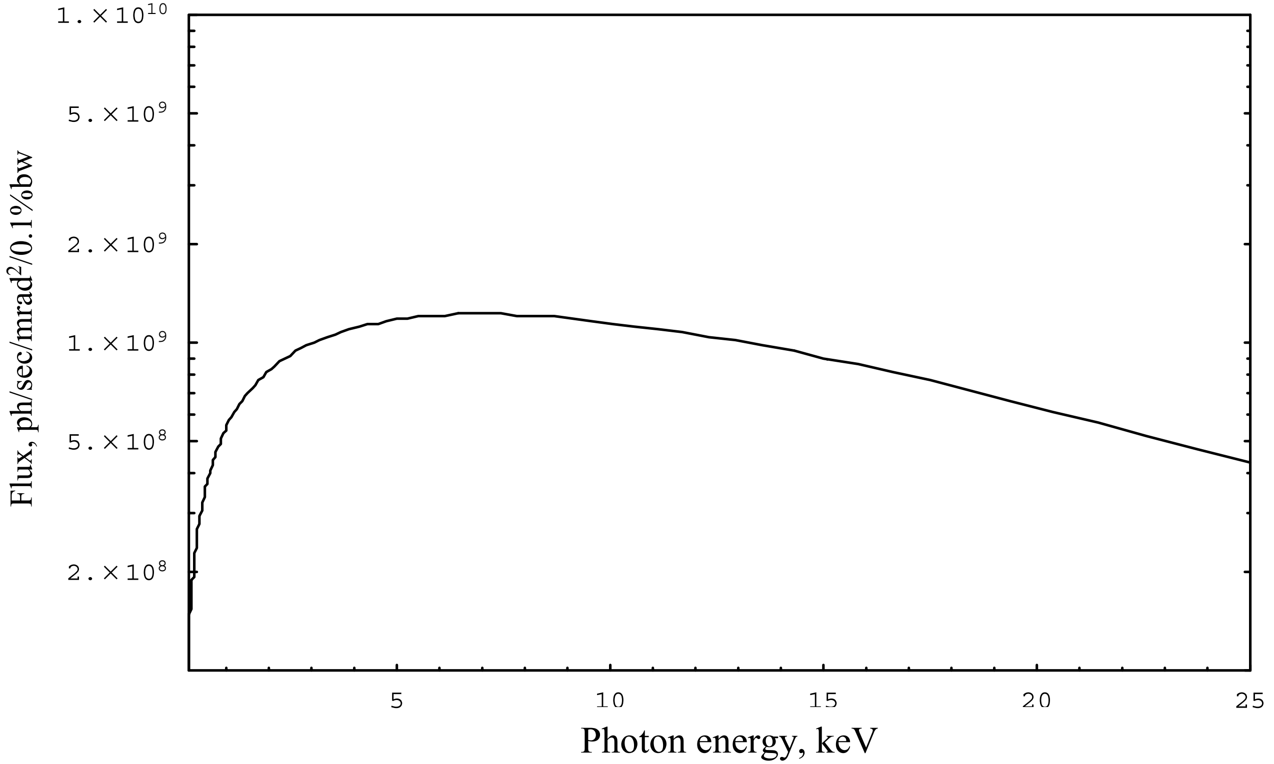
Laser/X-ray Timing Jitter



Femtosecond x-ray flux from undulator (talk by P.Heimann)



Femtosecond x-ray flux from magnet



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